

# Trampling Fragmentation Potential of lithic artifacts: an experimental approach

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## ABSTRACT

A proposal to estimate the Trampling Fragmentation Potential (TFP) on lithic artifacts from their metric attributes is presented. We apply a data mining technique known as decision tree to experimental datasets obtained in several trampling experiments. Results show that the ratio of area to thickness is the main element affecting the probability of breakage on lithic artifacts by trampling. Also, a maximum thickness value for lithic artifacts prone to be broken by trampling is estimated. Finally, we argue establishing threshold values for trampling potential allows distinguishing incidental fractures with similar traits and different origins.

**Keywords:** Trampling; Fragmentation potential; Lithics; Experiments; Decision tree.

## RESUMEN

POTENCIAL DE FRAGMENTACIÓN POR PISOTEO EN ARTEFACTOS LÍTICOS: UNA APROXIMACIÓN EXPERIMENTAL. Este trabajo presenta una propuesta para estimar el Potencial para la Fragmentación por Pisoteo (PFP) en artefactos líticos a partir de los atributos métricos de las piezas. Se aplica la técnica de *data mining* denominada árbol de decisión, para el análisis de datos experimentales obtenidos en diversas experiencias de pisoteo. Los resultados indican que la razón superficie/espesor es el elemento más influyente sobre la probabilidad de fractura de los artefactos sometidos a pisoteo. De modo complementario, se estima un valor máximo para el espesor de los artefactos líticos que pueden fracturarse por este proceso. Finalmente, el establecimiento de valores límite para la fragmentación por pisoteo permitiría diferenciar fracturas accidentales causadas por otros procesos.

**Palabras clave:** Pisoteo; Potencial de fragmentación; Lítico; Experimentación; Árbol de decisión.

## INTRODUCTION

Fragmentation is common among lithic assemblage and its causes and implications have been the focus of much archaeological research (*i.e.*, Crabtree 1972; Cotterell and Kamminga 1979; Johnson 1979; Odell 1981; Rondeau 1981; Bergman and Newcomer 1983; Fischer *et al.* 1984; Hiscock 1985, 2002; Odell and Cowan 1986; Whittaker 1995; Root *et al.* 1999; Shott

2000; Deller and Ellis 2001; Petraglia 2002; Miller 2006; Weitzel and Colombo 2006; Flegenheimer and Weitzel 2007; Lombard and Pargeter 2008; Tallavaara *et al.* 2010; Weitzel 2010, 2011, 2012; Jennings 2011, among many others). Lithic artifacts, considered one of the most durable cultural materials, have the potential to bear and preserve valuable information related to the formation of archaeological records (Hiscock 1985; Goldberg *et al.* 1993; Borrazzo 2004, 2006a,

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2010; Thiébaud *et al.* 2010a). Artifact fragmentation has been used to assess assemblage preservation and integrity, human occupation intensity, and taphonomic modifications to lithic artifacts themselves (Bordes 1961; Gifford-Gonzalez *et al.* 1985; Hiscock 1985, 2002; Nielsen 1991; Osborn and Hartley 1991; Borrazzo 2004, 2010; Ramos and Merenzon 2004; Eren *et al.* 2010, 2011; Thiébaud 2010, among others). Within this framework, we believe that understanding factors that influence lithic artifact breakage is a key issue in need of further investigation. In this paper we define artifact breakage or fragmentation as macroscopic damage (macrofractures) involving the whole artifact, as opposed to edge damage, and the research we present centers on the study of macrofractures.

Several archaeological studies have focused on the agents and processes involved in artifact fragmentation. Current archaeological knowledge indicates that lithic artifacts might break as a result of manufacture, use, deliberate breakage, and postdepositional or taphonomic processes (Crabtree 1972; Johnson 1979; Frison and Bradley 1980; Rondeau 1981; Nami 1983; Fischer *et al.* 1984; Root *et al.* 1999; Deller and Ellis 2001; Miller 2006; Weitzel and Colombo 2006; Borrazzo 2010; Weitzel 2010, among others). Moreover, the study of fracture surface markings suggests that several patterns of breakage are identifiable as the unequivocal effects of specific processes (Johnson 1979; Frison and Bradley 1980; Fischer *et al.* 1984; Quinn 2007; Weitzel 2010, 2012). However, bending (transverse) fractures –the most common fracture type in lithic assemblages– may result from a variety of taphonomic processes (Fischer *et al.* 1984; Cotterell and Kamminga 1987; Whittaker 1995; Weitzel 2010). The low diagnostic power of bending fractures, therefore, has severely limited their usefulness in studies designed to identify causes of lithic fragmentation.

Trampling is likely an important cause of lithic fragmentation but the process has been shown to result in numerous bending fractures (Fischer *et al.* 1984; Cotterell and Kamminga 1987; Whittaker 1995; Flegenheimer and Weitzel 2007; Weitzel 2010, 2012; Jennings 2011). Therefore, understanding the contribution of trampling to overall assemblage fragmentation patterns requires alternative lines of evidence. With this aim, this paper explores methodological tools to gauge the extent of human and faunal trampling in lithic assemblage fragmentation. A crucial first step, and the primary goal of this paper, is to identify which artifacts can and which cannot be broken by trampling. We analyzed relationships between experimentally produced lithic artifacts' metrics and whether they broke during five independent trampling experiments carried out by the authors. Experimental data is explored with a data mining technique called decision-tree (Quinlan 1986; Williams

2011) and a model with material expectations to assess Trampling Fragmentation Potential is presented.

## BACKGROUND

Trampling exposes lithic artifacts to complex high-energy processes that can alter both their shape and spatial position. Flakes have morphological attributes that allow us to determine whether their original shape was subsequently modified, which, in turn, permits the study of taphonomic processes that contributed to this modification. Thus, analysis of metric attributes (length, width, and thickness) and the ratios between them among complete artifacts may help us understand the intensity of the post-depositional processes that acted on an assemblage.

Several investigations have focused on the processes that can lead to artifact fracture (*i.e.*, Crabtree 1972; Cotterell and Kamminga 1979; Johnson 1979; Odell 1981; Rondeau 1981; Bergman and Newcomer 1983; Fischer *et al.* 1984; Root *et al.* 1999; Miller 2006; Weitzel and Colombo 2006; Weitzel 2010). Bordes and Bourgon (1951) were among the first exploring the effects of trampling on lithic assemblages. With the advent of experimental archaeology and studies of site formation processes, several trampling experiments were designed to test specific hypotheses. One of the first such studies was that of Tringham *et al.* (1974) who proposed a set of criteria for identifying edge damage caused by trampling: random distribution of flake scars, scars on a single surface of the flake, flake scars without patterned orientation or size but always elongated. This paper was discussed later by several researchers who were unable to replicate the results (Flenniken and Haggarty 1980; Mansur-Franchomme 1986; Pryor 1988). Gifford-González *et al.* (1985) describe an experiment designed to evaluate vertical artifact movements due to human foot traffic. They used a sample of 2000 obsidian flakes ranging in size from 3 to 13 mm and arranged half of them on a loam substrate and the other half on a sandy substrate. Their results showed both a higher fracture rate and the breakage of smaller pieces on the harder substrate (loam).

Pintar's (1987) experiment was designed to track horizontal and vertical displacements due to heavy human foot traffic on surface and subsurface lithic assemblages. She used basalt flakes between 2 and 12 cm, placed on a sandy substrate. Fractures –defined as those thicker than 1 mm– were the least frequent type of damage recorded. Pryor (1988) presents an experiment designed to define material signatures of trampling. The author arranged two sets of artifacts on substrates of different hardness, sandy and loamy. Nine hundred obsidian flakes of different sizes were



laid on a sandy beach and on a residential garden with loosely compacted loam that included rocks. He found that flakes between 12 mm and 25 mm are resistant to fracture. The experiment focused on edge damage; there are no references to fracture ratios, thickness, or other fracture traits. Jorge Merenzon carried out several experiments in 1983, 1984, and 1986 aimed at controlling the trampling effects of intense human foot traffic on lithic assemblages deposited in shell middens located along the Beagle Channel (Tierra del Fuego, Argentina). He placed lithic artifacts on loamy soils (dry and wet), loamy soils (dry and wet) with shell fragments added, and a fresh, complete shells substrate (dry and wet). In one set of experiments (Merenzon 1988), 511 flakes were deposited in two plots that were trampled for 28 days. The author observed that 90% of the sample was displaced either vertically or horizontally, or both. Regarding macrofractures, he reported that flakes trampled on the complete shell substrate exhibited the highest mass loss (30.5%). In addition, Merenzon observed that both macro- and microfractures were more frequent in the wet plot samples. Finally, he concluded that trampling is a non-linear process and proposed a sequence of three stages, at which particular phenomena predominate: 1) pronounced horizontal dispersal; 2) vertical migration, and 3) edge damage and stability (*i.e.*, no further displacement or breakage while conditions hold).

Osborn and Hartley (1991) created twelve experimental plots in Capitol Reef National Park (Utah, USA) to monitor the effects of livestock trampling, specifically post-depositional breakage, artifact visibility, and displacement. Plots included lithic artifacts and ceramic vessel fragments. After approximately six months of livestock grazing, the authors found that only eleven of the 589 original lithic artifacts exhibited fractures and that 22% of the lithic sample recorded horizontal displacement. Nielsen (1991) carried out six experiments to evaluate contradictory results reported by several published trampling experiments. Of his six experiments using obsidian flakes, bone, wood, bricks and sherds, five were conducted on dry consolidated surfaces with no vegetation and one on those same muddy gravel sediments after a heavy rain. The experiments focused mainly on vertical and horizontal displacement, general artifact damage, and patterns of ceramic breakage. Three plots included lithic artifacts. Among them, he assessed three types of damage: breakage, microflaking, and abrasion. Breakage occurred on 19 to 24.8% of the artifacts after trampling and it was more frequent on harder surfaces (24.8%), even though the number of crossings performed on another plot was larger (800 vs. 1500 crossings).

McBrearty *et al.* (1998) designed an experiment to evaluate edge damage due to trampling vs. deliberate

retouch. They used 1400 flakes of obsidian and a coarse chert ranging in size from 3 to 7 cm, which were arranged on two different substrates: compact, moist loam and unconsolidated sand. The highest breakage ratio was recorded on high density chert assemblage located on moist loam substrate (39%). The authors concluded that substrate was the most important factor influencing damage, followed by raw material and artifact density.

Eren *et al.* (2010) carried out an experiment to evaluate the effects of short-duration animal trampling on dry and water-saturated substrates. They used 120 limestone flakes that were trampled by buffalos and goats, and recorded horizontal and vertical displacements, artifact inclination, and breakage. The latter occurred only on two artifacts. Thiébaud *et al.* (2010b) carried out an experiment of bison trampling on flint and chert flakes and bone to evaluate disappearance, spatial displacements, edge modification, and fractures. They observed a fragmentation ratio of nearly 50%. Jennings (2011) conducted three flake fracture experiments testing damage due to manufacture, intentional breakage, and trampling. The goal of the trampling experiment was to break each flake by walking on it. The sample included twenty chert flakes, which were first placed on a dry, hardened silty clay surface with no vegetation cover. Each flake was then stepped on in a single step. Flakes that could not be broken in a single step were subjected to flake-on-flake trampling in which one flake was placed on the silty clay surface, two additional flakes were placed directly on top of it, and all three flakes were stepped on a single time. Nineteen out of twenty flakes were broken during this experiment: eight by a single step (single flake placed on the ground) and eleven during flake-on-flake trampling. The 19 broken flakes exhibited bending, radial, and Hertzian fractures. Bending fractures were the most common ( $n = 21$ ). The recorded average thickness at break was 3.48 mm in the trampling experiment. Pargeter (2011) assessed human and cattle trampling on dolerite, quartz, and quartzite flakes. Artifacts were placed on sandy clay soil with rock and sand inclusions. In each plot, half of each sample was buried at a depth of 10 cm and the other half was deposited just below the surface, to assess whether fracture occurrence was affected by depth below surface. Cattle ( $n = 40$ ) trampled the experimental plots for 15 minutes twice a day for 27 days. Human trampling was conducted by six individuals in sock feet, for a period of 1 hour per experiment. The author reported that 2.4% of the sample was broken during cattle trampling while human trampling produced fractures in only 1.5% of the flakes. Pargeter proposed that most fracturing takes place within the first few hours of trampling since, after that time, artifacts are generally covered with sediments and often protected from further fracturing.

However, nearly 50% of the cattle-broken assemblage was originally located 10 cm below the surface.

As this brief review shows, trampling studies focused primarily on: (1) natural/accidental edge fractures that can simulate intentional retouch or use wear (Tringham *et al.* 1974; Fischer *et al.* 1984; Mansur-Franchomme 1986; Pryor 1988; McBrearty *et al.* 1998; Lopinot and Ray 2007; Thiébaud 2010); (2) distinguishing macrofractures originated during production and use from those produced by trampling (McBrearty *et al.* 1998; Jennings 2011; Pargeter 2011); (3) the extent of horizontal and vertical displacement caused by trampling (Gifford-González *et al.* 1985; Pintar 1987; Merenzon 1988; Eren *et al.* 2010); and (4) differential rates of fragmentation by raw material type (Nielsen 1991; Osborn and Hartley 1991; McBrearty *et al.* 1998; Pargeter 2011). Specific traits of trampling fractures have seldom been identified, defined or proposed (Hiscock 1985; Cotterell and Kamminga 1987; Weitzel 2010, 2012; Jennings 2011; Pargeter 2013).

## MATERIALS AND METHODS

### Experiments

Data considered in this study were collected during five experiments in nine plots, carried out by the authors in Buenos Aires, Santa Cruz, and Tierra del Fuego Provinces, Argentina (Figure 1). These experiments involved various lithic raw materials, substrates, trampling agents, and durations (Table 1).

The first experiment was carried out by CW and Nora Flegenheimer in Necochea, Buenos Aires Province (Flegenheimer and Weitzel 2007) as part of CW's dissertation research on lithic artifact fragmentation (Weitzel 2010). Experimental artifacts were manufactured from Sierras Bayas orthoquartzites, the main lithic raw material used by hunter-gatherer groups in the Pampean Region (Flegenheimer *et al.* 1996; Bayón *et al.* 2006). One of two plots was established on



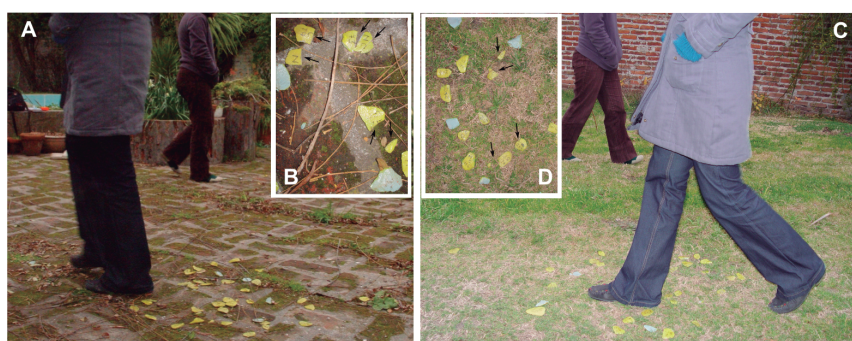
**Figure 1.** Locations of authors' trampling experiments. 1: Necochea (Buenos Aires); 2: La Verdadera Argentina Ranch archaeological locality (Santa Cruz); 3: Northern Tierra del Fuego.

a hard, compact substrate (brick) and the second one was established on loamy soil in a residential garden (Figure 2). One hour of intense human trampling was performed in each plot by experimenters weighing 50 and 60 kg, one wearing soft-soled shoes and the other wearing socks. Artifact fracture and movement were

Exp	RM	Substrate	Agent	t	N (fl)	N (F)	Fth (min/mean/max)	F%
Necochea	Ortho-quartzite	Loam	Human	1 hour	47	5	3/5/7 mm	10.6%
		Brick	Human	1 hour	52	14	3/5/7 mm	26.9%
LVA steppe	Lutite	Loam with gravels	Fauna	7 years	22	9	1/1.44/4 mm	40.90%
LVA track	Lutite	Loam with gravels	Fauna (livestock)	1 year	46	3	1/3.67/6 mm	6.52%
		Loam with gravels	Fauna (livestock)	1 year	54	3	2/3.67/5 mm	5.56%
Tierra del Fuego	Rhyolite, silicified rocks and lutite	Compact silty clay	Fauna	5 years	12	3	2/4/6 mm	20%
		Wet silty clay	Fauna	5 years	12	0	0	0%
Tierra del Fuego	Fine-grained silicified rocks	Compact silty clay	Human	20'	18	1	3 mm	5.55%

**Table 1.** Summary of the experimental data sets. Ref: Exp: Experiment; RM: raw material; fl: flakes; F: fracture; Fth: fracture thickness.





**Figure 2.** Necochea human trampling experiments. A: brick substrate plot; B: detail of brick substrate after trampling; C: general view of loamy soil plot; D: detail of loamy soil substrate after trampling. Arrows indicate fractured artifacts.

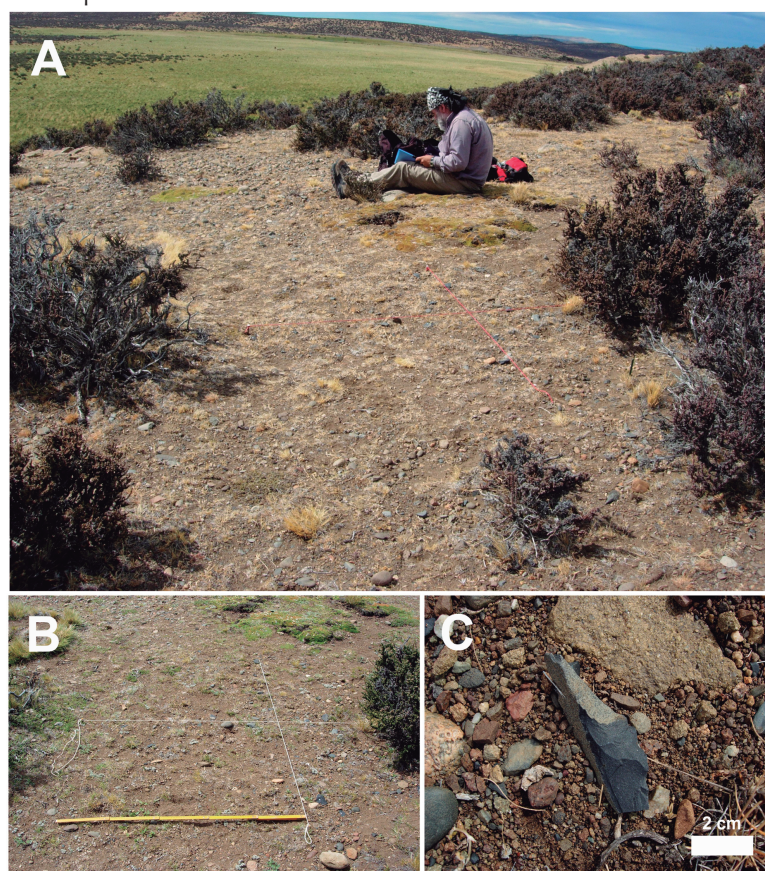
assessed every 10 minutes. Rotations, displacements, and fractures were recorded in both plots at the end of each experiment. Results indicate that fractures were far more common among artifacts in the brick plot (Table 1). In the loamy soil experiment, fragmentation occurred primarily during the first 20 minutes and then plateaued. Breakage ratios among the materials in the brick plot increased throughout the hour; in the last 10-15 minutes breakage was highest among already-broken pieces. Finally, all of the fractures were bending type, most of them transverse and perpendicular to the longitudinal axis (Flegenheimer and Weitzel 2007).

The other four experiments were developed in Fuego-Patagonia as part of the larger Magallania Archaeological Project directed by Luis Borrero (Borrero 2001a, 2001b). These long-term experiments focus on the study of taphonomic transformations in surface lithic assemblages located within different steppe environments. Two of these experiments were conducted in La Verdadera Argentina Ranch archaeological locality (LVA), in the southeastern Baguales Range (Santa Cruz Province; Borrero *et al.* 2006, 2007). All of the plots were established on loamy soils containing gravel. One experiment consisted of regular monitoring of a plot first established by KB at the end of 2004 (Borrazzo 2011a), and subsequently revisited in 2005, 2008, 2010, 2011, and 2012 to assess artifact movement, burial frequency, and fracture occurrence (Figure 3). The location of the plot away from roads and ranch houses suggests that main trampling agents are wild fauna (guanaco [*Lama guanicoe*], puma [*Puma concolor*], choique [*Rhea penatta*], foxes [*Pseudalopex*

*culpaeus* and *P. griseus*], and hare [*Lepus europaeus*]) as well as livestock (horse, cow, and sheep) that graze in the area. Experimental artifacts were manufactured from lutite, an immediately available raw material that dominates the local archaeological assemblages (Borrazzo 2006b, 2008).

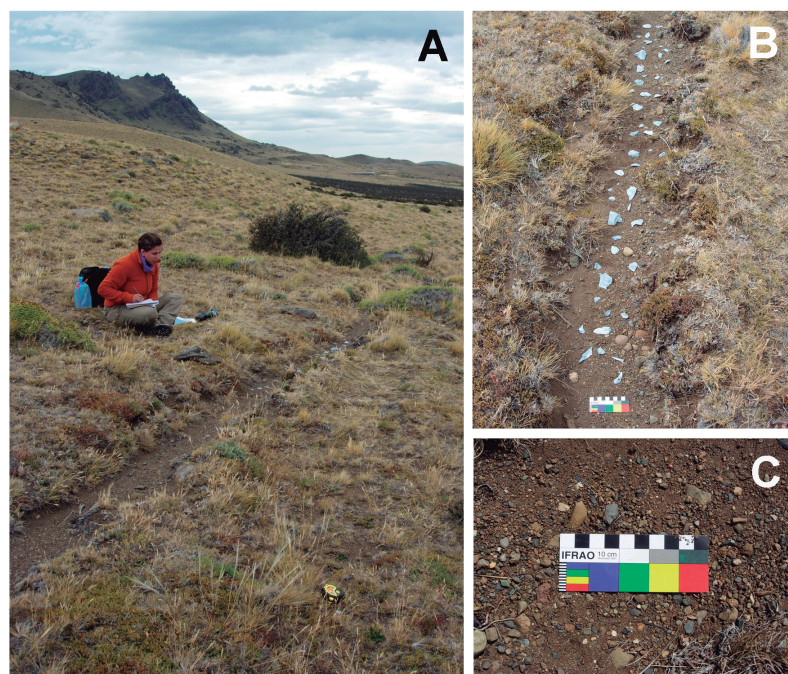
The second experiment carried out in LVA consisted of two plots established by CB in 2011 (Balirán 2012, 2014). The primary goal of this experiment was to assess fracture patterns of faunal trampling, specifically large cattle. Plots were located on active livestock tracks, away from roads and ranch houses (Figure 4). As in the previous case, all artifacts were manufactured from lutite. The plots were assessed for movement, burial frequency, and fractures in 2012.

The final two experiments were developed by KB in northern Tierra del Fuego (Borrazzo 2010, 2013a). The substrate in the study area (aeolian-lacustrine plains, Vilas *et al.* 1986-1987, 1999; Borrazzo 2012, 2013b)



**Figure 3.** LVA steppe plot. A: general view of the environmental setting; B: LVA steppe plot; C: detail of plot substrate.





**Figure 4.** LVA animal track experiment (plot A). A: general view of the environmental setting; B: plot A in year 2011; C: detail of track substrate.

is primarily composed of clay (with a small amount of silt). The first experiment in Tierra del Fuego included three plots established in 2007 and assessed in 2008 and 2013. Here we will consider data collected at plots A and C (Borrazzo 2010, Figure 5). Potential trampling agents in the area are guanaco and livestock (cow and sheep) but evidence suggests that guanaco

perspective in lithic artifact analysis was first expressed by Hiscock (1985) and has in recent years been acknowledged and applied by an increasing number of scholars (Nash 1993; Paddayya and Petraglia 1993; Burroni *et al.* 2002; Bordes 2003; Borrazzo 2004, 2006a, 2011a, b; Thiébaud *et al.* 2010a; Borrero 2011; Domínguez-Rodrigo *et al.* 2011; Eren

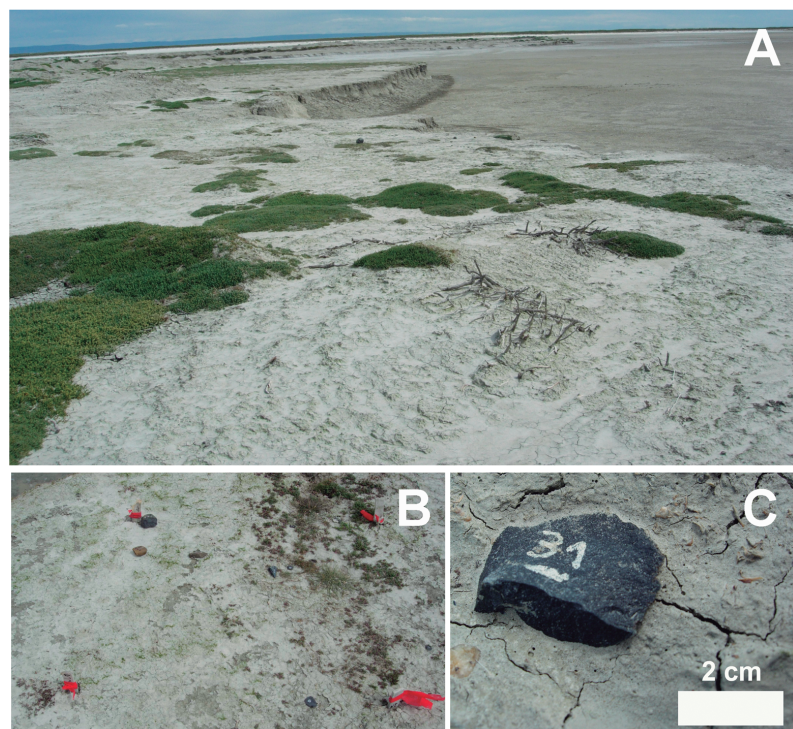
is the primary trampling agent (presence of dung and footprint on the plots, guanaco sightings near plots). Finally, a human trampling experiment was conducted near plot A. The experiment included one plot (silty clay substrate) and two agents (55 and 80 kg) wearing rubber-soled shoes. Local lithic raw materials employed for Tierra del Fuego experiments include rhyolite, lutite, and fine-grained silicified rocks.

Table 1 summarizes the results of the five experiments presented above and assessed in the following section. It bears noting that only 38 of 263 artifacts broke during the experiments (Figure 6).

#### **Analytical Methods**

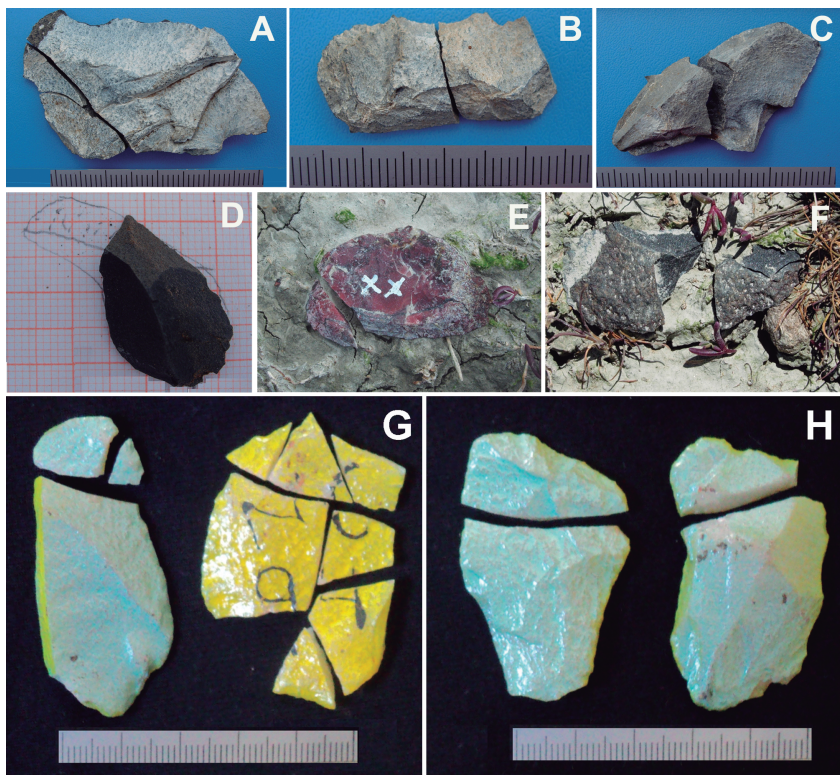
The need for a taphonomic perspective in lithic artifact analysis was first expressed by Hiscock (1985) and has in recent years been acknowledged and applied by an increasing number of scholars (Nash 1993; Paddayya and Petraglia 1993; Burroni *et al.* 2002; Bordes 2003; Borrazzo 2004, 2006a, 2011a, b; Thiébaud *et al.* 2010a; Borrero 2011; Domínguez-Rodrigo *et al.* 2011; Eren *et al.* 2011, among others). Our theoretical approach is that of lithic taphonomy, which we define as the archaeological and actualistic study of the effects of natural and cultural agents and processes on lithic artifact assemblages that occurred after their deposition in an archaeological context (Borrazzo 2004, 2006a). In studies of site formation processes (Schiffer 1983, 1987), the study of lithic taphonomy focuses on artifact and assemblage morphological and spatial attributes to understand their post-depositional history and paleobiological and paleoenvironmental contexts.

To assess which variables might explain the observed condition of artifacts –which might have been broken by trampling and which not– we analyzed the maximum length (L), maximum width (W), maximum thickness (T), and raw material of experimental lithic artifacts using R 2.11.0 (R Development Core



**Figure 5.** Tierra del Fuego plot A. A: general view of the environmental setting; B: Tierra del Fuego plot A; C: detail of experimental artifact deposited on silty clay substrate.





**Figure 6.** Examples of broken artifacts from trampling experiments. A-C: LVA livestock track plots; D: LVA steppe plot (drawing below the artifact indicates its original shape and the missing fragment); E-F: Tierra del Fuego plot A; G: Necochea hard surface plot; H: Necochea soft surface plot.

Team 2011). We also included two ratios, maximum length/ maximum width/ maximum thickness (L/W/T) and area to thickness (A/T)<sup>1</sup>. We previously proposed these rates as potentially significant variables as we observed that absolute artifact measures are not always themselves conclusive on its condition (Borrazzo 2004, 2010; Weitzel 2010). For example, a very thin artifact will not break when subject to trampling if it offers a small surface of encounter (small size). Furthermore, we expected its probability of breakage will also diminish as the difference for its length and width measures approximates to 0 (*i.e.*, similar values for length and width). Finally, we proposed those artifacts exhibiting “spherical shape” (*i.e.*, similar measures for its three shape axis, *sensu* Zingg 1935) are the less sensitive items to trampling fragmentation (Borrazzo 2004). Thus, we considered L/W/T and/or A/T rates –as possible syntheses of some of the existing relationships among main shape axis– may be significantly related to artifact condition.

As evidenced by the studies cited in the literature review and our own experiments, fragmentation ratios are quite variable, even among similar substrates and trampling agents (*i.e.*, Osborn and Hartley 1991; Eren *et al.* 2010; Thiébaud *et al.* 2010b; Jennings 2011; Pargeter 2011). We believe this is due in part to the fact that, although raw

material, trampling agent, and substrate were explicitly detailed in those experiments, the measures for the three main shape axis (length, width, and thickness) of each artifact subjected to trampling were not systematically informed and considered in further analysis. As we will show here, all of these morphometric attributes are a significant factor in fracture occurrence since they condition the fragmentation potential of each artifact and, thus, the expected rate of assemblage fragmentation due to trampling. The statistical characterizations of metric attributes and indices for the experimental data sets considered in our study are summarized in Table 2.

The data were analyzed using a data mining technique known as decision trees. Data mining (DM) is defined by Williams (2011) as the science of intelligent data analysis. DM consists in the application of specific algorithms and statistical methods for extracting patterns from large data sets. Technically, it is the process of finding correlations or patterns among dozens of fields in large relational databases (Fayyad *et al.* 1996; Williams 2011). It is also described as a process of building models, since the information extracted from data is often expressed through models (Williams 2011). Decision trees (DT) are a classic learning system of data mining or knowledge discovery in databases, and a class of statistical methods that generate predictive models. These tree-shaped structures represent sets of decisions; they consist of a *root* (the most representative attribute that describes the data set); *branches* (a classification question or probability, one of the possible alternatives or courses of action available at that point); and *leaves/ nodes* (cases within the dataset, a point where a choice

	Max. Length	Max. Width	Max. Thickness	Area/ Thickness	Length/Width/ Thickness
N (observations)	263	263	263	263	263
Minimum	10	9	2	27.86	.020
Maximum	74	93	49	427.50	.88
Mean	35.26	33.66	8.18	151.71	.17
Median	35	31	7	145.71	.15
Variance	179.05	180.61	21.70	3909.22	.01
Std.dev.	13.38	13.44	4.66	62.52	.12

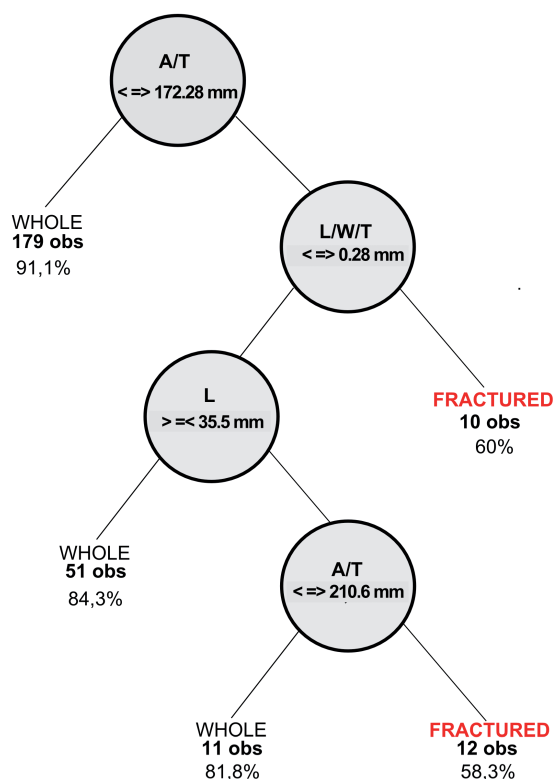
**Table 2.** Experimental data set descriptive statistics. All measures in mm.



must be made) (Berson *et al.* 1999; Rokach and Maimon 2010; Williams 2011). The system (decision tree) learns from examples in a non-incremental manner: the system is presented with cases relevant to a classification task and it develops a DT from the top down, guided by frequency information in the examples (Quinlan 1986; Berson *et al.* 1999; Williams 2011). DT inducers are algorithms that automatically construct a DT from a given data set. Specifically, the algorithm seeks to create a tree that explains as perfectly as possible all the available data, that is, to find the optimal DT by minimizing the generalization error (Rokach and Maimon 2010: 151). Algorithms frequently used in DT building include ID3 (Iterative Dichotomiser 3), C4.5 –an extension of ID3– CART (Classification and Regression Tree) and CHAID (Chi Square Automatic Interaction Detection). These algorithms construct a model that explains the given data generating a predictive model by providing a set of rules that can be applied to a new (unclassified) dataset (Quinlan 1986; Palace 1996; Berson *et al.* 1999). In this work we considered artifact condition (complete or broken) as the target.

## RESULTS

The decision tree we obtained for the condition of artifacts exposed to trampling is shown in Figure 7. The diagram reads from the top down. According to



**Figure 7.** Decision tree for the condition of experimental artifacts subject to trampling.

the DT, the ratio of artifact area to maximum thickness (A/T) is the first significant variable (root) to explain artifact condition (complete or broken).

The decision tree, then, shows –given the variables in our experimental data set– that artifacts with A/T values less than or equal to 172.28 mm were not broken by trampling. Thus, the condition of approximately 91% of the experimental dataset (unbroken) is explained by the model. The first node (following the right branch) indicates that artifacts with an A/T greater than 172.28 mm were broken after trampling when their length/width/thickness ratio (L/W/T) was greater than or equal to 0.28. If L/W/T is smaller than 0.28 (left branch of the first node) the DT produces a second node where length is the decisive variable: artifacts equal to or longer than 35.5 mm remained unbroken after being trampled (left branch of the second node), while shorter artifacts are evaluated by another condition, indicated in the third node (right branch). Here, A/T becomes important again since short artifacts ( $L < 35.5$ ) with A/T values below 210.6 mm should not break when subjected to trampling (left branch of the third node), but *should* break if A/T is greater than or equal to 210.6 mm.

In order to assess if the relationships between artifact condition and the variables selected by the DT were statistically significant, we perform a Student's *t*-test for artifact condition against each DT variable. Results show that the relationship between A/T and artifact condition is the only statistically significant (see Table 3). Therefore, factors other than A/T may change their role in the model as new data is submitted to the decision tree. Still, although we do not expect the role of A/T to change, its “switch-point” values may change as new data or datasets are considered. The DT presented here will only be useful for samples holding metric values and raw materials similar to the ones in our experimental data set.

Next we included in the decision tree the contextual variables shown by our trampling experiments to affect damage outcomes; particularly trampling agent and substrate. Considering all the variables together (raw material, metric, and contextual), the decision tree arrived at exactly the same structure for trampling expectations. That is, raw material, agent, and substrate were not selected by DT as determining factors for artifact condition after trampling events. It is worth

	p	T
Thickness	.08	1.72
Length	.054	-1.96
Width	.55	-.59
Area	.39	-.85
Area/Thickness	.00007	-3.6
Length/Width/Thickness	.24	-1.16

**Table 3.** Student's *t*-test for artifact condition (significance level: .05).

considering that the influence of raw material may increase with obsidian artifacts because of its high fragility. Further experimentation is needed to assess this statement.

So far, DT selected A/T ratio as the key variable affecting artifact condition when subjected to trampling. Student's *t* test showed that the relation between these variables is the only statically significant. Furthermore, DT predicts that artifacts exhibiting A/T values below 172.28 mm are unlikely to be broken by trampling. Thus, DT predictions suggest that the occurrence of fractures on pieces exhibiting smaller A/T values should be attributable to other processes. Based on these results, we propose that *the ratio of area to thickness is a key in the assessment of trampling fragmentation potential* (TFP) in lithics. Our results indicate that TFP is primarily conditioned by artifacts' metric attributes and that other factors such as substrate and trampling agent may influence the frequency of fragmentation but not whether an artifact can be broken by trampling. For example, the results from the Necochea experiment showed that there was a significant relationship between substrate hardness and fracture ratio (Weitzel 2010), as demonstrated previously by other researchers (Gifford-Gonzalez *et al.* 1985; Nielsen 1991; McBrearty *et al.* 1998). A further important observation from our study is that in none of the experiments fracture section thicknesses of more than 7 mm were recorded. Therefore, we propose to add thickness as a complementary variable to assess artifact TFP. If we consider 7 mm the maximum thickness that can be effectively broken by trampling given the other morphological characteristics represented in our experimental dataset, then tentatively, we can suggest that any artifact with an A/T value above 172.28 and 7 mm or more thick cannot be broken by trampling. Of course, the 7 mm thickness threshold is based on trampling agents weighting up to approximately 600 kg; agents above this weight (*i.e.*, elephants or several extinct mammals, Borrero and Martin 2012) might break artifacts 7 mm thick; further actualistic research is required in areas that include or included such large-bodied animals.

## DISCUSSION

Based on the results of our analyses using decision trees and experimental observations of attributes that influence lithic artifact breakage by trampling, we propose two threshold values for assessing TFP. The first is the ratio of area to thickness, selected as the DT root for predicting artifact condition (threshold value for current sample is 172.28 mm). So far, A/T is the only variable among those considered for this study exhibiting a statistically significant relationship with artifact condition. The second threshold value we

propose for artifact TFP assessment derives from our actualistic observations: thickness. Given our dataset, artifacts whose sections are up to 7 mm thick can be broken by trampling and therefore have high TFP.

These threshold values explain artifact condition for the dataset obtained from our five trampling experiments, but the DT also serves as a predictive model. That is, we can evaluate new data (experimental or archaeological) relative to this model, so long as it is within the morphological range, and suite of raw materials, substrates and agents. Meeting these criteria, the model will predict artifacts' condition (broken or whole), and we can then compare artifact's actual condition to the modeled predictions to assess whether trampling is the most likely mechanism to explain the fragmentation pattern observed in any given assemblage. Furthermore, the model can be refined with new experimental data; as it incorporates more "training" data, the model's predictions become more accurate and applicable to more diverse assemblages. The DT also shows that, among our sample, other variables (length/width/thickness and artifact length) contribute to artifact condition, though they are not statistically significant. The size of the available sample remains small, and the role of these variables in explaining artifact condition may change as more data are introduced to the DT. We will be better able to judge the relative importance of these and other variables when the available experimental sample is diverse enough to represent the morphological universe of flaked artifacts. The model presented above is useful for assessing lithic assemblages with attributes (metric variables and raw materials) similar to those considered in our data set (Table 2), but assemblages exhibiting different values for artifact morphometric attributes are not strictly comparable and therefore specific experimental data are needed for the construction of a new DT.

We recommend a cautious use of threshold values to assess whether a lithic assemblage was subjected to trampling by calculating the frequency of whole flakes with a high TFP (here,  $A/T > 172.28$  mm and maximum thickness  $< 7$  mm). If a sample contains intact artifacts with a high TFP, that lithic assemblage may not have been intensively affected by trampling processes. On the other hand, if high TFP flakes are scarce or absent from an assemblage, the analyst will need to determine whether such artifacts were ever present in the original assemblage before making a claim for trample damage since flake morphological attributes depend on tool production techniques and parent material size. To address this, we suggest a thorough examination of broken flakes to understand an assemblage's original composition (Hiscock 2002). Lastly, TFP expectations provided by the model permit special consideration of broken artifacts with fracture thicknesses greater than

7 mm. In this case, fracture-type analyses might help us distinguish fractures generated through production technique, knapping errors, or deliberate breakage (Weitzel 2010).

### CONCLUDING REMARKS AND PERSPECTIVES

The decision tree technique generated a model that explains and predicts the attributes that determine lithic artifact breakage by trampling. The model predicts the condition of an artifact (broken or whole) after trampling based on its metric attributes and their relationships. Given these predictions, we can interpret the likelihood that trampling was a leading cause of artifact fragmentation in a given assemblage. Moreover, the model can be trained with new datasets, which will improve the accuracy of its predictions. It is worth repeating that the dataset used to generate the critical A/T and length values reported here was relatively small. A more diverse sample is necessary to generate an A/T threshold applicable to any lithic assemblage. Nonetheless, this exploratory research suggests a promising new avenue for trampling fragmentation research which may ultimately generate threshold values able to evaluate both the causes that originated fragmentation in given lithic assemblages and the impact of trampling. In addition, the accuracy of the A/T values can be adjusted to specific contexts by generating large experimental datasets for the specific context under study, that is, by replicating the archaeological substrate, potential trampling agents, and lithic artifact morphometric attributes.

Finally, we suggest that future work to improve our knowledge of lithic artifact fragmentation due to trampling requires: increasing the experimental sample; increasing the sample's diversity (different artifact morphologies, lithic raw materials, substrates, etc.); adding new variables and reporting the morphometric characteristics of experimental datasets subjected to trampling as a standard in trampling experiments.

Trampling and its effects have been a frequent topic in actualistic research in archaeology. However, further work is necessary to improve our knowledge of the complex processes that lead to the fragmentation patterns seen in archaeological assemblages worldwide.

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#### NOTES

1. Area=L x W; L= artifact maximum length (in mm); W=artifact maximum width (in mm). All measures were made with a digital caliper.